Geophysical characteristics and structural composition of clay rocks in the terrigenous complex of the southeastern part of the West Siberian oil and gas bearing province

A Ezhova[1,2] and N Nedolivko[1,3]

[1] Department of Geology and Mineral Exploration, Institute of Natural Resources, National Research Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia

Email: [2] eav@tpu.ru, [3] nedolivkonm@yandex.ru

Abstract. The basic attributes identifying the clay rock composition in the terrigenous complex of the southeastern part of the West-Siberian platform have been determined, based on the correlation of structural composition and geophysical data, including induced potential logging, apparent resistivity, induction logging, radioactive and caliper logging. According to the obtained results it is possible to identify above-mentioned rocks in well logs, even under conditions of limited core samples, their application in well log correlation and back stripping.
Key words: geophysical well logging, the West-Siberian oil and gas bearing province, terrigenous complex, clay rocks, back stripping.

1. Introduction

In the southeastern part of the West Siberian platform the petroleum-bearing formations are composed of clastic, clay carbonaceous and carbonate rock alterations. However, siliceous, aluminous and ferrous rocks have also been revealed. Under the conditions of limited terrigenous profile core samples from Jurassic sedimentary formations and those emerging problems in log analysis interpretation [1], one of the major tasks in the development of an improved profile study of enclosing sedimentary rocks in oil-gas reservoirs is the integration of geophysical and lithological data. In this case one aspect of the above-mentioned problem is to assign rock structural composition to their geophysical field characteristics.

2. Subject and Research Methods

The study data included the following: core samples of clay and carbonaceous rocks and their produced thin sections; results of XD and quantitative spectrum analyses and geophysical well logging data package including induced potential logging (SP log), apparent resistivity logging, inductive electro-magnetic logging, radioactive and caliper logging, describing the drill logs from the south-eastern area of the southeastern part of West Siberian oil and gas bearing province, Tomsk region: Sobolinaya (Sob.), Gerasimovskaya (G), East-Gerasimovskaya EG), Kalinovaya (K), Fobosskaya, Nizhne-Tabaganskaya (NT), South-Tabaganskaya (ST) fields.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

3. Results

The clay rocks are composed of 0.01 mm particles, where the basic rock-forming clay minerals are kaolinite, hydromica, montmorillonite, involving alternating layers, such as illite-montmorillonite. Chlorite, ferrum and aluminium oxides and hydroxides and silica could also be important components. Two genetic types of clay rocks have been revealed-chemogenic and clastic. Chemogenic clay rocks within the formation are classified as residual products of weathering crust, i.e. structured clay residual rocks, according to B.B. Polinov [9] and V.P. Kazarinov [5]. The cross-sections show that there are several different structured clay residual rocks, the mineralogical composition of which was revealed by XD analysis data (18 samples).

1. Clays are light gray, practically white in color with sparse angular fragments of highly weathered siliceous-ferruginous rocks (figure 1A). The thin sections show (figure 1B) that the basic rock body embraces kaolinite with fine-grained quartz and siderite as fine oolites, sometimes oxidized oolites.

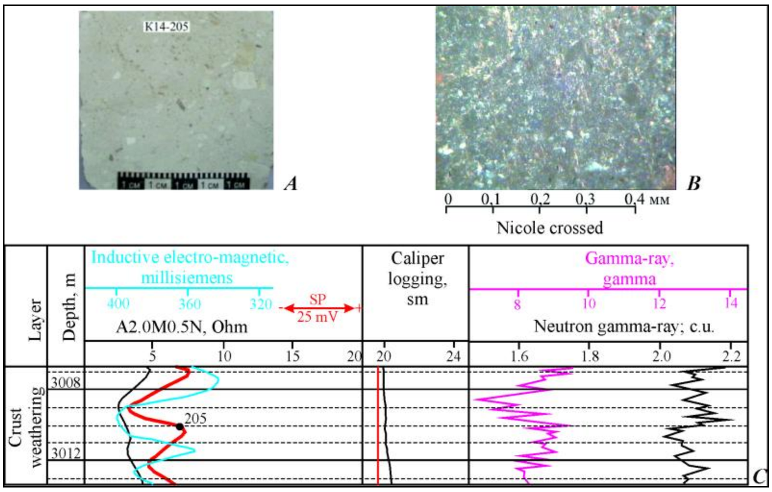

Figure 1. Structure (A), petrographic composition (B) and geophysical characteristics (C) of kaolinite clay rocks of the crust weathering:
A, B, C – Well 14 Kalinovaya; depth=3010.0 m.

According to the XD analysis data the mineral percentage is the following: kaolinite (45-62 %), chlorite (8-10 %), hydromica (8-15 %), montmorillonite (4-5 %), siderite (7-15 %), quartz (10-13 %). The well log shows that clays are defined by positive SP curves, low (up to 5 Ohm) electrical resistance, high (from 350 millisiemens) conductivity, insignificant increase (3-4 cm) of the borehole diameter, increased radioactivity (up to 10 γ) and increased (2.0-2.2 pulse/min.) neutron gamma-ray curve values (figure 1C). Based on the mineralogical composition and the evidence of intensely altered angular fragments and their view location in the profile – in breccia roof, the described clays are neo-formed residual rocks. The latter (according to B.B. Polinov [9]) is a structured clay residual rock horizon formed during the Permo-Triassic period due to the decomposition of loose coarse-grained sediments.

2. Siliceous-clay rocks are white in color with horizontal and vertical cracks (figure 2A).

In the thin sections (figure 2B), as in the previous ones, the basic rock body embraces kaolinite with fine-grained quartz and extra fine hydromica crystalloids. XD analysis data revealed the fact that this composition is as follows: kaolinite (40-45 %), chlorite (5-7 %), hydromica (30-35 %), montmorillonite (up to 5 %), quartz (25-30 %), siderite (often oxidizied) up to 10%. In single samples powder quartz contributed the white color to the rock. The rocks show the following characteristic features (figure 2C): positive SP anomalies, low (about 5 Ohm) electrical resistance, high (from 200 millisiemens) conductivity, insignificant increase (up to 22 cm, if rated value is 19 cm) of the borehole diameter, rather high radioactivity (up to 40γ) and increasingly intensive (1.8-2.0 pulse/min.) neutro gamma-ray curve values. The above-mentioned factors – evidence of powder quartz, mineral composition and location in the profiles, i.e. top of siliceous rocks (spongolites and quartzites) indicate that these clays could be classified as para-residual siliceous sedimentary rocks.

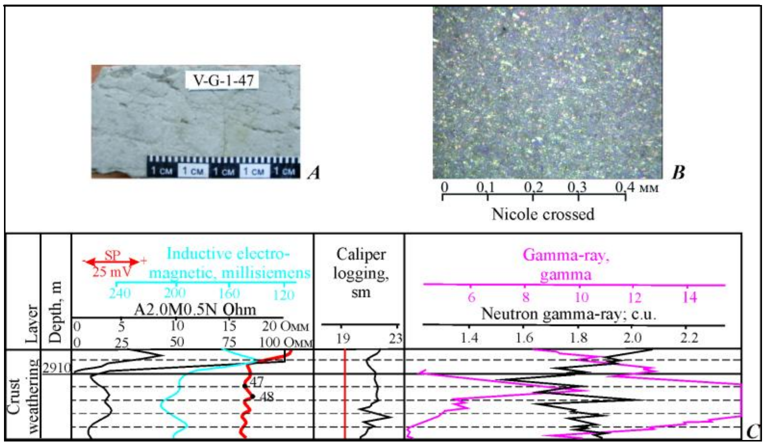

Figure 2. Structure (A), petrographic composition (B) and geophysical characteristics (C) of siliceous clay rocks of the crust weathering:
A, B, C – Well 1 East-Gerasimovskaya;
depth=2912.0 m.

3. Chemogenic clay rocks include a limited number of chloritized clays underlying mafic effusive – clay ortho-residual rocks. According to the XD analysis data the mineral percentage is the following: kaolinite (15-20 %), chlorite (25-30 %), hydromica (30-35 %), montmorillonite (up to 5 %), siderite (often oxidizied) up to 10 %, quartz (up to 5%). Geophysical characteristics of lay rocks are similar to the ones described above. Clastic clays are the result of erosion and redeposition of the weathering crust and pre-existing sedimentary rocks. The mineralogical clay material alteration processes in the diagenetic period in the case of free water loss and compaction of sediments. Iron sulphides, carbonates, sulphates, iron oxide and iron hydroxide minerals are formed in clay rocks. During catagenesis clay rocks are affected by increasing temperatures and pressure involving interstital pores, resulting in compacted clays and argillites, plasticity loss and gradual mineral deswelling. Primary clay rock alteration occurs during metagenesis, whereas clay rocks become foliated and further form mud shales and argillaceous slates. According to the degree of composition, clay rocks include the following sequence: clays- compacted clays–argillites–mud shales–argillaceous slates, within which only clays and compacted clays exhibit plasticity and exchange properties. Due to these properties the transformation of clay minerals, alteration of their mineralogical composition and replacement of minerals under amenable conditions occur during the post-sedimentation period. In this respect, the composition of clay rocks in sedimentary thicknesses is rarely correlated to the sedimentation environment [6]. However, particular differences in the mineralogical composition of the diversely genetic clay rocks can be observed within the study area (100 sample results based on XD analysis).

The marine green clays (figure 3A), formed in relatively deep waters in Early Cretaceous and Late Jurassic period [4], are predominately composed of hydromica (35 %), alternating hydromica-montmorillonite sequences (22 %), montmorillonite (10 %), chlorite (18 %) and kaolinite (15 %). Thin-walled pelecypodas, ichthyofauna and foraminifer can also be observed.

The thin sections (figure 3B) show insignificant quartz impurities, fine-flaky hydromica and glauconite inclusions. The well log (figure 3C) shows that clays are defined by low (up to 5 Ohm) electrical resistance, relatively high conductivity (100-120 millisiemens), positve SP anomaly, increased radioactivity (14-16γ), the increasing of the borehole diameter from 24 to 28 cm, if rated value is 19 cm.

Callovian-Oxfordian clays (Nizhne-Vasugan subsuite), formed in shallow marine and coastal environments [8], include hydromica (54 %), chlorite (16 %), alternating hydromica-montmorillonite sequences (16 %), montmorillonite (4 %), and kaolinite (10 %). Fauna remains, ichnofossils (figure 4A) and plant detritus can also be observed. Predominate hydromica with oriented arrangement of flakes showing micro-cleavage, as well as pelitomorphic textured siderite or siderite concretions can be distinctively observed in the thin sections (figure 4B). Geophysical characteristics (figure 4C) of clay rocks are analogs of above-described ones.

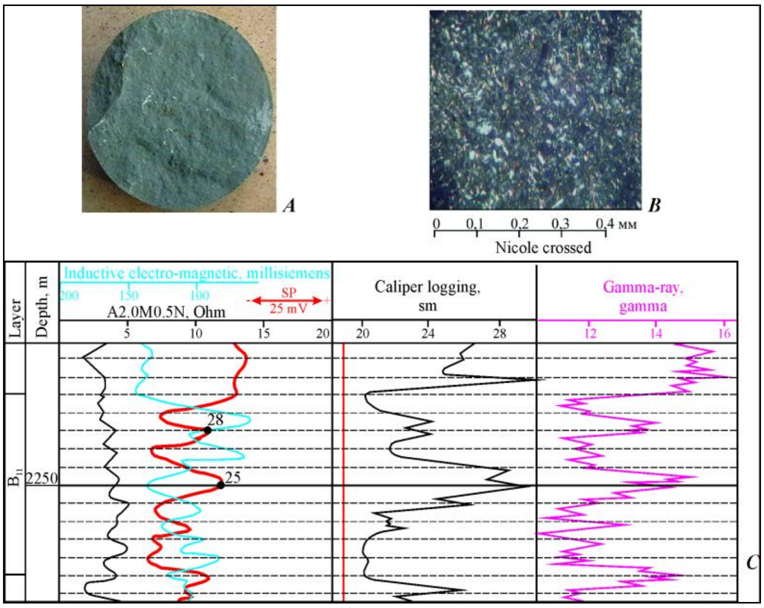

Figure 3. Structure (A), petrographic composition (B) and geophysical characteristics (C) of chlorite-hydromica clays of marine genesis:
A, B, C – Well 213 Sobolinaya; depth= 2225.0 m

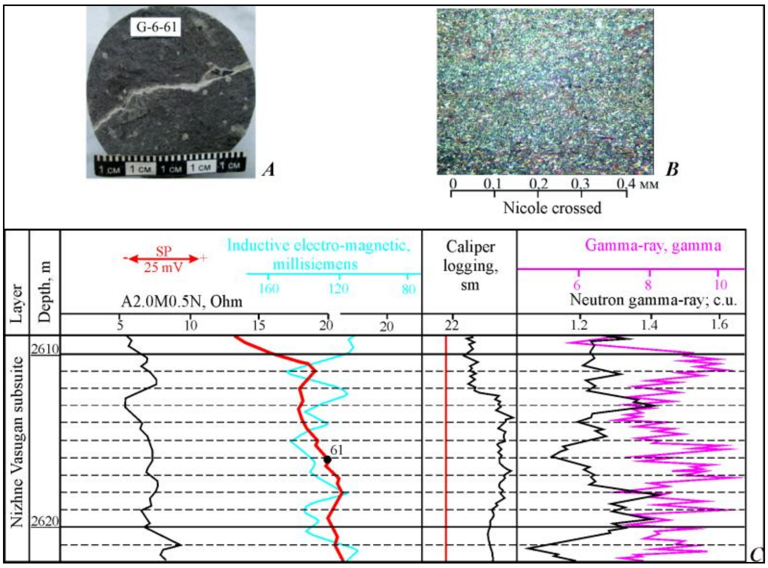

Figure 4. Structure (A), petrographic composition (B) and geophysical characteristics (C) of Nizhne-Vasugan subsuite hydromica clay rocks:
A, B, C – Gerasimovskaya-6; depth= 2616.0 m.

Early and Mid. Jurassic clay rocks, accumulating in laustrine-swamp, deluvial-proluvial-alluvial fresh shallow marine and lagoon environments [3], exhibit variable polymineral composition: include kaolinite (13-44 %), chlorite (12-20 %), hydromica (30-50 %), and alternating hydromica-montmorillonite sequences (4-7 %). Small siderite concretions – up to 10 %, scattered organic matter, ichnofauna and phyllopoda accumulations were also revealed; rocks contain concretions of siderite and pyrite, plant detritus mass, burrow traces and terrigenous impurities. The well log showed these clays are defined by low (5-10 Ohm) electrical resistance, high (120-150 millisiemens) conductivity, increased radioactivity (14-16γ), low (1.2-1.6 pulse/min.) intensity of neutron gamma-ray curve values, the increase of the borehole diameter up to 6-8 cm, positive SP anomaly curves with negative deviation in case of increased terrigenous impurity content.

Togur subsuite brown argillites (figure 5A), apparently formed in fresh marine waters [2], include kaolinite (28-32 %), chlorite (14-18 %), hydromica (30-40 %) and alternating hydromica-montmorillonite sequences (5-25 %). Small siderite concretions (up to 10 %), scattered organic matter, ichnofauna and phyllopoda accumulations were also revealed. The thin sections show finest quartz impurities and extra fine plant detritus amid fine hydromica, siderite matter and brown bituminous substance (figure 5B). The well log (figure 5C) showed increased (15-22 Ohm) electrical resistance (in comparison to the above-described ones), high conductivity (up to 150 millisiemens), high radioactivity (20-22γ), low intensity of neutron gamma-ray curve values (1.4 pulse/min.), the increase of the borehole diameter (more than 40 cm), high DTS values (ΔT – to 335 ms/m).

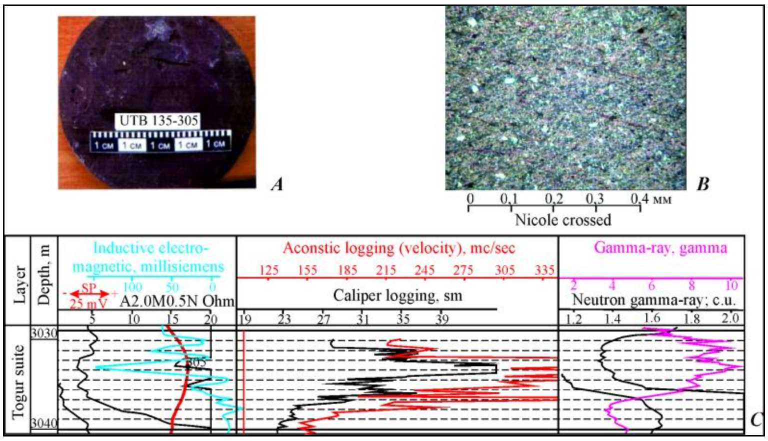

Figure 5. Structure (A), petrographic composition (B) and geophysical characteristics (C) of Togur subsuite bituminous hydromica argillite with pyrites and fine-grained quartz impurities:
A, B, C – Well 135 South-Tabaganskaya; depth=3033.5 m.

Bazhenov suite bituminous argillites (figure 6A), formed in deep-sea conditions [7], have extremely heterogeneous mineralogical composition. Hydromica and chlorite (43-44-72 %), with tributary kaolinite (2-15 %) and alternating hydromica-montmorillonite sequences (9-22 %) and montmorillonite (3-10 %) are predominate in the clay fraction. The thin sections show abundance of bituminous substance, pigmenting the rocks brown. Silicified and calcilated sponge spicula remains, radiolaria and foraminifera were also revealed. Thin weaving micro-fractures with or without bitumen and abundant tiny pyrite and quartz inclusions were also observed (figure 6B).

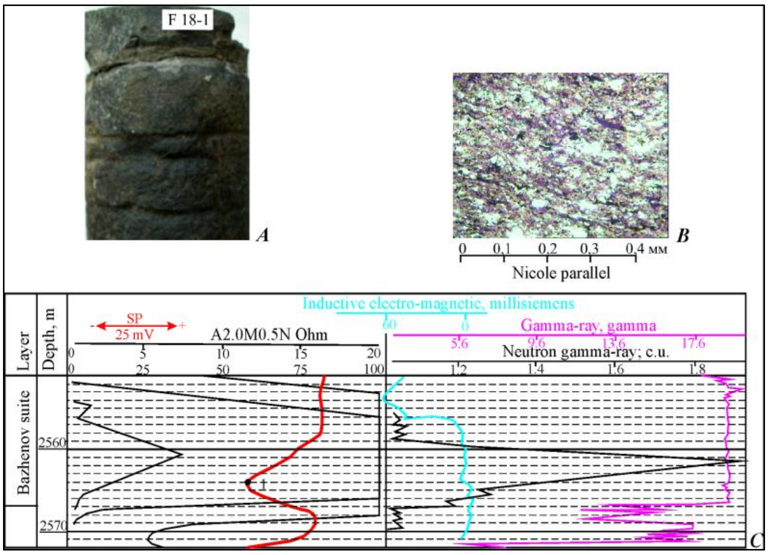

Figure 6. Structure (A), petrographic composition (B) and geophysical characteristics (C) of Bazhenov suite bituminous hydromica argillites with pyrite: A – Well 18 Fobosskaya, depth=2598.0 m; B – Well 18 Nizhe-Tabaganskaya, depth=2564.0 m; C – Well 18 Fobosskaya; depth=2598.0 m.

Bazhenov suite argillites have clear geophysical characteristics: significantly high electrical resistance (100 Ohm) and high radioactivity (more than 40γ), high (2.0-2.2 pulse/min.) neutron gamma-ray curve values if any carbonate interlayers, while, typically, undifferentiated SP curve. However, there are profiles with fractured sections in the argillite itself, indicating negative SP curve deviations of up to 20 mV (figure 6C).

4. Conclusions

The basic characteristic features of clay and carbonaceous rocks and coals in the profiles of studied formation are the following: chemogenic clays are residual products of crust weathering formation – structured clay residual rocks in the profile are neo-formed residual rocks according to petrographic and mineralogical composition (during decomposition of loose coarse-clastic rocks) and para-residual (due to siliceous rocks) and ortho-residual rocks (during weathering of effusives); the mineralogical composition of chemogenic clays depends on the composition of the rocks, showing a significant abundance of kaolinite, chlorite and hydromica content; deswelling component (montmorillonite) is not more than 5 % and differently oxidied quartz and siderite could also be found in the samples; geophysical attributes of clay rocks of crust weathering does not depend on the mineralogical composition, in broader terms: low electrical resistance, significantly high (up to 400 millisiemens) conductivity, positive SP anomalies, insignificant increase of the well diameter, increased raadioactivity values and intensive gamma rays; clastic rocks in investigated formation is related to compacted clays, with kaolinite, chlorite and hydromica content and different alternating hydromica-montmorillonite sequences and dependable of marine montmorillonite-hydromica clays with chlorite; continental: hydromica-kaolinite, hydromicas, often sideritized with abundant flora remains; in geophysical logs homogeneous clays show low electrical resistivity, increased conductivity, high radioactivity, increasing well diameter, positive PS anomaly; terrigeneous impurities initiate negative PS curve deviations, while bituminous matter causes the increase of electrical resistivity and radioactivity; deswelling minerals decrease in agrillites which lessen the plastic property to further fracturing or fracture porosity, which, in its turn, reveals negative deviations on SP curves.

References

[1] Ezhova A V 2012 *Geological interpretation of geophysical data* (Tomsk: Publishing House of Tomsk Polytechnic University) (in Russian)

[2] Ezhova A, Merkulov V, Chekanstev V and Abramova R 2015 Litho-Geophysical Structure of Paleozoic-Mesozoic Contact Zone in North-Ostaninsk Oil Field (Tomsk Oblast) *IOP Conf. Ser.: Earth Environ. Sci.* **24** 012013

[3] Ezhova A, Ostankov A, Panova E and Abramova R 2015 Stratigraphy and correlation of Lower-Middle Jurassic sediments in SE West-Siberian petroleum-bearing province *IOP Conf. Ser.: Earth Environ. Sci.* **24** 012014

[4] Ezhova A V 2008 Refinement of the Geological Model of the Verhnesalat Oil Field (Tomsk District) based on lithofacies investigations of the Middle-Upper Jurassic Productive Bed. *Earth Sciences* **419(2)** 235–238

[5] Kazarinov V P 1958 *Mesozoic and Cainozoic deposits in the Western Siberia* (Moscow: Gostoptehizdat) (in Russian)

[6] Nedolivko N M 2001 Clay minerals of the Jurassic in the eastern part of Nurolsk Basin *Proceedings of the International Scientific and Technical Conference Geological and Mining Education. Oil and Gas Geology* (Tomsk: Publishing House of Tomsk Polytechnic University) 181–184 (in Russian)

[7] Nedolivko N M 2014 Lithogenetic types and Bazhenov suite sediment formation conditions based on Well U-M 413 data (Tomsk Oblast) *Academic Journal of West Siberia* **5**(10) 95–100

[8] Perevertailo T, Nedolivko N and Dolgaya T 2015 Vasyugan horizon structure features within junction zone of Ust-Tym depression and Parabel megaswell (Tomsk Oblast) *IOP Conf. Ser.: Earth Environ. Sci. Scientific and Technical Challenges in the Well Drilling Progress*, **24** 012023 doi:10.1088/1755-1315/24/1/012023

[9] Polyinov B B 1934 *Weathering crust. Processes of the weathering. General facies, forms of weathering and their distribution*. (Leningrad: Publishing house of the USSR Academy of Sciences) (in Russian)